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Quick scan environmental impact assessment of the St. Eustatia harbour extension

Diana Slijkerman
Bas van Maren
Dolfi Debrot
Johan Stapel
Erik Meesters
Narangerel Davaasuren
Jan van Dalfsen

Deltares rapportnr. 1205206-000
IMARES rapportnr. C085/11

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Project	Reference	Pages
1205206-000	1205206-000-ZKS-0001 CO85/11	42

Key words
St. Eustatius, environmental impact, dredging, port development

Summary
At St. Eustatius a project has started for the improvement and expansion of the Seaport St. Eustatius. The planned activities related to the project need to be evaluated in order to comply with the legal requirements for a licence from the competent authority Rijkswaterstaat Noordzee in the Netherlands.

A quick scan of the potential environmental impact for the planned activities regarding the St. Eustatius harbour extension was commissioned by Rijkswaterstaat Noordzee. This quick scan was performed within limited time and based upon limited background information. No additional research on site was performed. Consequently, this report provides an environmental impact assessment based only on a review of literature and expert judgement.

Within the project it is foreseen that an estimated 10.000 m^3 of sediment will be dredged from the turning basin and dock in the new harbour and from the old harbour. The dredged material will be disposed of in the sheltered inner harbour and south of the breakwater. This deepening of the St. Eustatius harbour and associated activities can potentially negatively impact the environment (directly) through:

(1) Destruction of habitat on the dredged site and on the site where the dredge material is deposited
(2) The amount of sediment that will be dispersed into St. Eustatius coastal waters, and the cascading impact thereof on marine habitats
(3) Noise in marine habitats caused by the placement of piles and moorings

The resulting deepened harbour, the disposal sites and changes in future use may cause long term (indirect) negative impact on the environment due to:

(1) Dispersal of the dredge spill deposits, and thereby threatening marine habitats
(2) Increased turbidity due to harbour sediment erosion, increased sediment trapping and more shipping movements
(3) Changing current and wave patterns, thereby threatening key monuments of human history close to the shoreline
(4) The increased risk of spills (fuel, oil, bilge water), introduction of nutrients and marine litter, and introduction of invasive species (bio pollution)

These potential impacts have been investigated in this report and have resulted in the following findings, which are summarized in table 1:

The tidal and residual currents around St. Eustatius are weak and estimated to be up to 20 cm/s. Near the harbour area, the residual flow is probably dominantly north. The wave height is low throughout the larger part of the year, except during hurricanes and tropical storms. From December to April cold fronts in Florida regularly generate swells from the north to northeast

("brown seas"). These events occur once or twice a month, last for a day to a week, and may generate swell waves 3 to 5 m high.

The marine substrate in the harbour area consists of a hard substratum overlying a more loosely packed conglomerate including sand and pebbles. This hard substratum consists of large rock fragments and cemented conglomerates. Removing this hard layer makes the underlying softer material available for erosion, especially since the deepened area will be exposed to the winter swells and has a water depth where the swells may break (and hence lead to high near-bed shear stresses). The risk for increased levels of suspended sediment due to erosion is probably small, but depends on the fine silt content of the sediment to be exposed. The available information does not indicate the presence of such fine material in the sediment.

During the dredging works, the sediment spill is expected to be limited. It is assumed dredging will be done during calm conditions. Some sediment will enter the water column during dredging, but due to the low ambient currents most will immediately settle from suspension. If present, silt and flocculated mud will be transported 1-2 km northward. Unflocculated mud can be expected to mix with ambient currents within days, leading to only limited increase in turbidity.
Storage of dredged material occurs in the sheltered inner harbour and south of the breakwater. Little dispersion of this sediment is expected during the dredging and storage activities partly due to the planned placement of bubble screens.

Over longer timescales, the removal of the hard layer will probably lead to higher turbidity in the harbour during storms. The winter storms are associated with southward currents, and therefore some of this sediment may be transported south of the wind breaker.

It is expected that deepening of the harbour will lead to a minor change in alongshore transport in the inner harbour, but will not affect alongshore transport north of the old harbour or south of the breakwater. The wave height near the ruins just south of the old harbour will probably increase due to deepening which may have a small effect on the coast.

Based on the above findings and expert judgement regarding sediment transport and turbidity changes the following conclusions are drawn on the potential impact on the environment:

The sediment that enters the water during dredging works is expected to settle relatively quickly, leading to limited sediment-plumes and turbidity. Therefore, no mayor or irreversible impact from dredging works is to be expected on the surrounding habitats. This is based on the assumption that fine silt is not present at the site. However, if these sediments are present, habitats up to 1-2 km north of the harbour can be affected. The impact is estimated, however, to be limited due to the low expected volumes.

Dredging works will impact living organisms at the dredged site and deposit- sites, covering a total area of approximately 1-2 ha (dredged and dredge-deposit site). Recovery is likely to occur over time if environmental conditions permit. This may take up to several years in case of removal of climax stage ecosystems such as coral reefs and seagrass habitats.

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Direct impact on marine mammals due to pile driving and placement of moorings are considered to be negligible as the migrating season has already passed and noise levels are considered to be relatively low.

During the deposition of the dredged sediment at the two locations, no impact on surrounding habitats is expected due to the minor dispersion and mitigation measures taken (bubble sheets).

Unless added measures are taken it is expected that the dredge deposit on the south side of the breakwater and south of the old harbour will erode and will be dispersed during storm conditions. The rate at which this deposit will erode, and how much that contributes to overall turbidity during the storm-event, cannot be predicted based on available information.

An adverse impact of the deposited sediment over longer timescales on surrounding habitats cannot be excluded. Erosion of the southern deposit during storm events or hurricanes is likely to occur.
This means that it cannot be ruled out that an extra total volume of 7000m^3 sediment can be transported towards the southern reserve during a single hurricane event, potentially smothering coral and seagrass habitats. This might lead to severe impact on some species of corals and sea grasses. A significant part of the southern reserve is covered with these species. Current species coverage and abundance is not known, and therefore impact cannot be quantified.

Besides the intrinsic ecological value of the habitats of the southern reserve, the southern reserve holds many important dive sites. The environmental quality of the southern reserve habitats is therefore of high importance to the sustainable economic development and prospects of St. Eustatius. Any risk of deterioration of the southern reserve through resuspension of the dredged material and deposition within the southern reserve should be considered with caution and necessary preventive actions should be taken.

Potential indirect impacts on historical monuments could occur as a result of slightly increased wave heights in the harbour but are expected to be minor.

Indirect impact due to more extensive use of the harbour is expected to be a risk, but hard to quantify. Maintenance dredging is not expected, and if needed, the impact due to sediment suspension will no doubt be less than that of the dredging related to this extension, thus limited (assuming calm conditions and no silt content). Risk of bio-pollution is likely. In order to assess actual impact and proper measures, monitoring should be considered.

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Table 1. Overview of both immediate and long-term expected impacts of planned actions or changed situations due to the harbor extension project on various ecological and historical values in the direct vicinity. Non-urgent actions that may be necessary on the long-term are not indicated.

Immediate impacts of Planned action	**levels of expected irreverisble negative impacts on:**					**short-term**
			sand		**historical**	**additional**
	corals	**seagrass**	**community**	**cetaceans**	**structures**	**action needed**
dredging	minor	minor	minor	none	minor	none
deposited dredge north	minor	minor	minor	none	none	none
deposited dredge south	minor	minor	minor	none	none	none
pile-driving and moorings	none	none	none	none	none	none

Longterm-impacts of changed situation	**levels of expected irreverisble negative impacts on:**					**short-term**
			sand		**historical**	**additional**
	corals	**seagrass**	**community**	**cetaceans**	**structures**	**action needed**
subsurface sediment exposure	minor	minor	minor	minor	none	none
deposited substrate north location	minor	minor	minor	none	none	stabilize
deposited substrate south location	medium	medium	minor	none	none	**stabilize**
changed wave action	none	none	none	none	minor	none
cargo shipping	risk	risk	risk	risk	none	none
passenger shipping	risk	risk	risk	risk	none	none

Preventive actions should focus on the deposited sediment in the southern corner of the breakwater and lack of information on silt and mud content. Suggestions are to:

- Retrieve information on silt, mud and chalk content in the dredging area
- Make sure sediment deposits cannot erode towards southern reserve. Proper constructions should be considered with the contractor and island bureau
- Halt dredging and deposit activities temporarily in case of elevated seawater temperatures and during rough seas (to avoid multiple stress)
- Monitor surrounding habitat quality (reefs and seagrass) over time
- Monitor future use and related pressures and mitigate as considered needed

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Version	Date	Author	Initials	Review	Initials	Approval	Initials
1.0	July 2011	dr. D. Slijkerman		dr.ir. T. van Kessel	TvK	ir. T. Schilperoort	
		dr. D.S. van Maren	BM	dr. Chris Klok			
		dr. D. Debrot					
		dr. J. Stapel					
		dr. E. Meesters					
		drs. N. Davaasuren					
		drs. J.A. van Dalfsen					

State
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1 Introduction

1.1 Scope and aim of quick scan

The Executive Council of the Public Entity of Sint Eustatius started a project for the improvement and expansion of the Seaport St. Eustatius. The planned activities related to the project need to be evaluated in order to comply with the legal requirements for a licence from the competent authority Rijkswaterstaat Noordzee in the Netherlands. At present, the project has not been assessed on its environmental impact.

Rijkswaterstaat Noordzee commissioned Deltares and IMARES to conduct a quick scan on the potential environmental impacts of the project, based upon which a decision will be taken regarding the licensing procedure. Due to time constraints and limitations in available information, this report provides only a quick scan on potential environmental impacts in the western coastal zone of St. Eustatius. No additional field research was performed.

The report includes two assessments: the environmental impact related to direct activities during the planned construction works, and secondly the assessment of indirect, longer-term impacts resulting from the actual physical changes in the harbour and in the predicted future use of the harbour (foreseen situation 2030).

Impact is assessed on ecological elements as corals, seagrasses and marine mammals (including protected species). St. Eustatius is rich in archaeological features along the coast, and possible impacts on this element are taken into account as well.

The aim of this report is to assess whether the planned activities are likely to cause permanent and irreversible damage to the various ecosystem elements (coral, seagrass habitats, marine mammals) and archaeological values and the possibility of recovery.
If elements are likely to be affected, recovery potential is mentioned.

This report is NOT a thorough environmental impact assessment, but only comprises a Quick scan based upon expert judgement. Therefore, the conclusions are not to be used in any other scope than this report.

Acknowledgements

We thank Kate Walker and Jessica Berkel of STENAPA and Roberto Hensen of LVV St. Eustatius for their useful suggestions and for pointing out useful information sources on short notice.

1.2 Methods

The assessment was conducted in three steps:

1. Quick scan 1: retrieve knowledge of the hydrodynamics in the harbour area, and of the sediment & sea bottom characteristics in the harbour area. Therefore, the governing hydrodynamics was evaluated through a literature study, followed by an inventory of available marine substrate data. The likely fate of dredge spill and dredge disposal was analysed.
2. Quick scan 2: retrieve knowledge of the environment (corals, seagrasses, marine mammals) and its vulnerability to relevant pressures. A literature review, satellite imaging and personal observations were combined to describe the current status. Vulnerability aspects were reviewed and combined with expert knowledge.
3. Combine steps 1 and 2 to draw conclusions on possible impact of the planned activities

2 Planned activities and related pressures

2.1 Construction work

Dredging
The contractor will be dredging the St. Eustatius harbour at two locations (blue in Figure 2.1):
(1) The turning basin and dock in the new harbour, north of the breakwater, to a depth of 6.5 m below reference level (present depth between 4 - 7 m)
(2) The old harbour to a depth of 3.25 m (present depth between 1.5 - 4 m)

Dredge deposition
An estimated 10.000 m^3 of sediment is planned to be disposed of in two areas (yellow in Figure 2.1):
(1) 7000 m^3 will be disposed of in a triangle southeast of the windbreaker
(2) 3000 m^3 will be disposed of in a quarter circle south of the old harbour

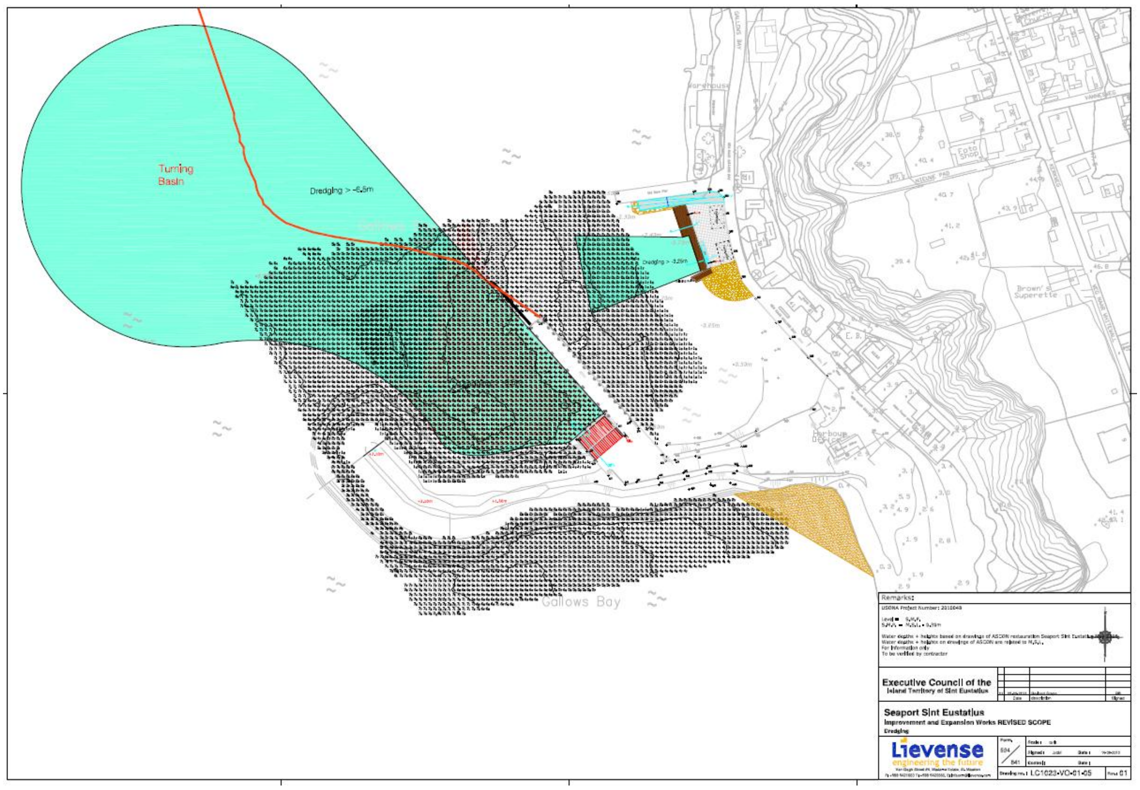

Figure 2.1 Map of the dredging works (blue) and disposal sites (yellow) plotted over the bathymetric survey.

2.2 Placement of piles and moorings

Pipe pilings so called "breasting dolphins" will be placed 40 m apart behind the main breakwater for mooring vessels of 60-90 ft in length and up to 5000 DWT. These 1778 mm diameter pipe pilings will have to be driven to a depth of 16 m below sea level (or 9.5 m below the seafloor). Also, similarly one such dolphin will be placed at the end of the existing pier. Calculations by Geotron (Ponte 2010) show that driving alone is not sufficient to reach such depths and that drilling will be required. These activities will cause underwater sound.

The moorings will be eco-friendly manta ray moorings intended for vessels of 20-50 ft in length. The manta ray moorings are driven to a depth of some 1.5 m below seafloor surface using conventional hydraulic equipment to reach a medium dense layer for acceptable strength for this vessel size-class. The placement of these moorings produces little sound and will have no immediate or long-term measurable effect on cetaceans in the vicinity.

For the constructions of the slipway and dinghy dock on the shore, plate-foundations will be used. This will produce no significant marine sound.

2.3 Future activities (2030)

To determine the indirect impact of the harbour extension it is important to know the expected harbour activities in future, in this assessment defined as 2030. Haskoning (Kateman and Bos 2010) reports projected shipping activities and tourist activities in 2030. A summary is presented in Table 2.1.

Table 2.1 Overview of activities in 2030

Activity	**Periodandduration 2030**	**intensity 2030**	**factor increase compared to 2010**
Harbour activities			
cargo shipping	Yearround, each day	332 per year	1.2
passenger vessels (ferries, cruise, - yachts)	Yearround, 1-2 days	21 per year	3.4
Auxiliary vessels	Yearround, <1 day	365 per year	1
yachting	sailing season 1-3 days	456 per year	7.7
maintenance dredging	potential increase due to increased tonnage	?	?

Due to the extension of the harbour, it is expected that especially passenger vessels and yachting increases in frequency, with respectively factor 3.4 and 7.7 compared to 2010. These two activities are assessed on their possible impact on the environment in chapter 6.

Maintenance dredging is currently not taking place. Although the Haskoning report (Kateman and Bos 2010) does not report this to be an activity in 2030, the authors assume that with increased tonnage of cargo vessels, maintenance dredging might be an indirect activity to consider in 2030.

2.4 Pressures to the marine environment related to the harbour extension project

The deepening of the harbour (direct) may negatively impact the environment (directly) through

1) Destruction of habitat on the dredged site and on the site where the dredge material is deposited
2) The amount of sediment that will be dispersed into St. Eustatius coastal waters, and the cascading impact thereof on marine habitats
3) Noise in marine habitats caused by the placement of piles and moorings

The presence of the deepened harbour (indirect) may negatively impact the environment (indirectly) by

1) Dispersal of the dredge spill deposits, and thereby threatening marine habitats
2) Increased turbidity due to harbour sediment erosion, increased sediment trapping and more shipping movements
3) Changing current and wave patterns, thereby threatening key monuments of human history close to the shoreline
4) The increased risk of spills (fuel, oil, bilge water), introduction of nutrients and marine litter, and introduction of invasive species (bio pollution)

2.5 Risk of cumulative impact

The primary cause of mass bleaching of corals is high water temperature. Other stressors can have a cumulative impact that weakens corals, making isolated bleaching and eventual death possible. Sources of stress on coral communities include elevated water temperatures and bright sunlight, diseases, pollution, salinity changes, and sedimentation from activities such as dredging.

In other words, dredging in times of bleaching events due to elevated water temperatures will possible results in cumulative impact on corals possibly additional mortality.

Based on Current Coral Bleaching Thermal Stress Levels at CRW Satellite Virtual Stations (NOAA website,http://coralreefwatch.noaa.gov/satellite/vs/alerts/vs_summary_stress_current.txt July 4th) , the Caribbean region near St. Eustatius does not show thermal stress at this moment.

This information does not include recent bleaching events of which the reef has to recover or additional stress from upcoming sedimentation. Physiological recovery from bleaching events may take up to a year, while recovery in terms of percentage cover may take up to decades after serious bleaching events. For example, in June 2011 on Bonaire, *Montastrea* spp. corals were still recovering from the bleaching in late 2010.

3 Geomorphology and predicted changes due to activities

Approximately 10.000 m^3 will be dredged and disposed in the vicinity of the harbour. The questions to be answered are:

(1) How much of the dredged sediment will be brought in suspension?
(2) Where will suspended sediment be transported to?
(3) How stable are the disposed deposits?
(4) How will deepening of the harbour affect wave propagation?

In order to answer above questions, a first estimate is made of the governing hydrodynamics through a literature study, an inventory of available soil data is discussed, and the fate of dredge spill and dredge disposal is analysed.

3.1 Hydrodynamics

3.1.1 Waves

During most of the year, winds are from the northeast to east and are fairly constant, force 2 to 3 Beaufort (Kateman and Bos, 2010). Since St. Eustatius harbour is located on the leeward side of the island, such low wind speeds do not generate significant wave heights. However, regular swell waves (with a period of 10-20 seconds) generated further away reach the harbour area. For about 80% of the time, the swell on St. Eustatius comes from the southwest while about 20% of the time, the swell comes from the northeast and southeast (Kateman and Bos, 2010). The height of these swell waves is not reported but probably not very high. Two conditions exist during which significant wave heights occur: during winter storms (December-April) and during the hurricane season (July-October).

Kateman and Bos (2010) report the occurrence of ‘brown seas’, occurring once or twice per month during the period December-April. These are apparently generated by cold fronts in Florida during winter storms. On such occasions, heavy swell (waves of 3 to 4 m, but occasionally up to 5 m) comes from the north to northwest with strong currents and undertow. Such ‘brown seas’ usually last one or two days but sometimes a week.

The Leeward Antilles, including St. Eustatius, are within the hurricane path (Figure 3.1). These storms generate high waves and strong currents. Tropical storms and category 1-2 hurricanes pass over St. Eustatius typically once every 5 years (top panel in Figure 3.2), in the period from July to December (lower panel in Figure 3.2). Destructive category 3-5 hurricanes occur every 10 years.

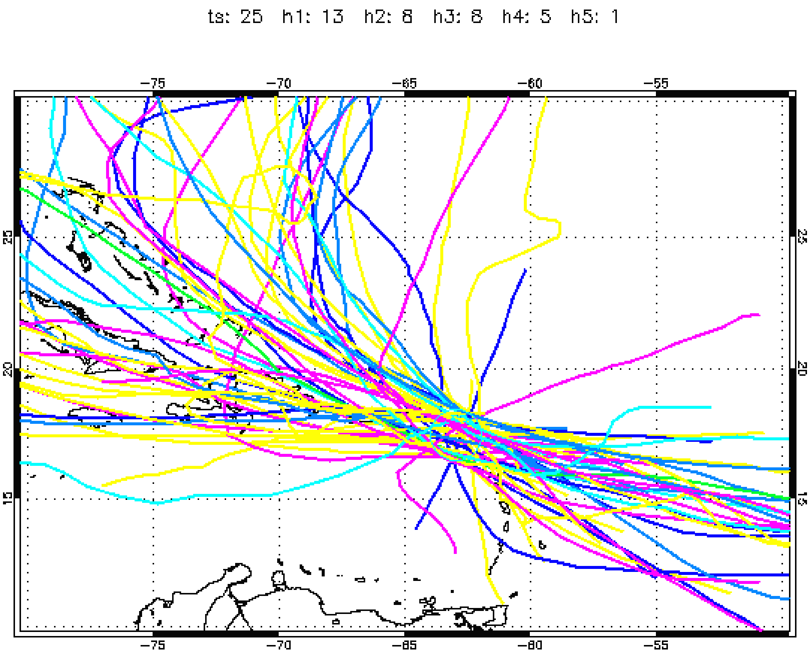

Figure 3.1 Trajectory of tropical storms (yellow) and hurricanes category h1 (pink), h2 (blue) h3 (light blue), h4 (cyan) and h5 (green) that passed over St. Eustatius between 1851 and 2010. (source: www.stormcarib.com).

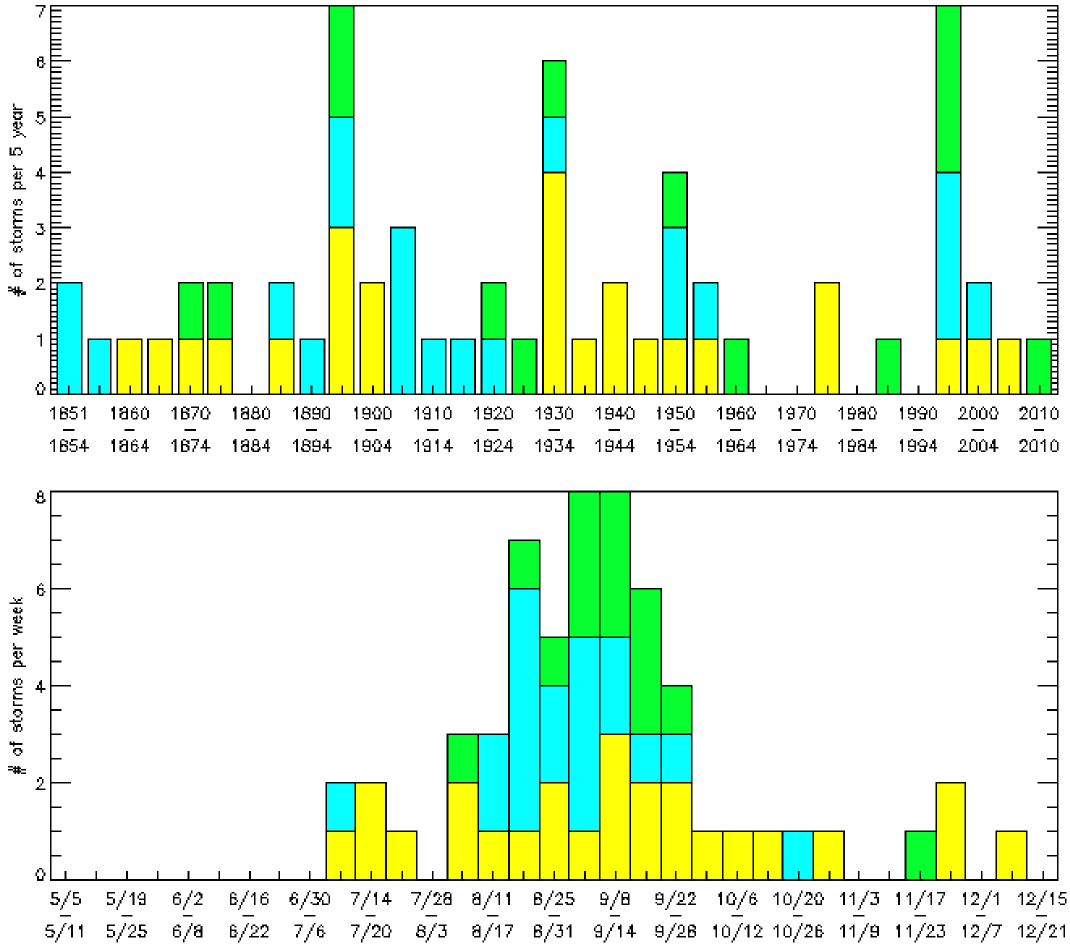

Figure 3.2 Occurrence of storms and hurricanes passing over St. Eustatius between 1851 and 2010: tropical storms (yellow), hurricanes category 1-2 (blue) and hurricanes category 3-5 (green) (source: www.stormcarib.com). The number of storms per 5 years is given in the top panel, most of which occur from July through October.

It should be realized that heavy seas also result from storms passing the Caribbean further away from St. Eustatius. From 1851 to 2010 25 tropical storms, 21 h1-h2 hurricanes and 14 h3-h5 hurricanes passed over St. Eustatius, but 150 tropical storms, 75 h1-h2 hurricanes, and 40 h3-h5 hurricanes pass through the Eastern Caribbean (Figure 3.3).
So while approximately 0.4 storms or hurricanes pass over St. Eustatius annually, 1.7 storms/ hurricanes traverse the entire Eastern Caribbean. Heavy storm-induced waves can therefore be expected close to two times per year.

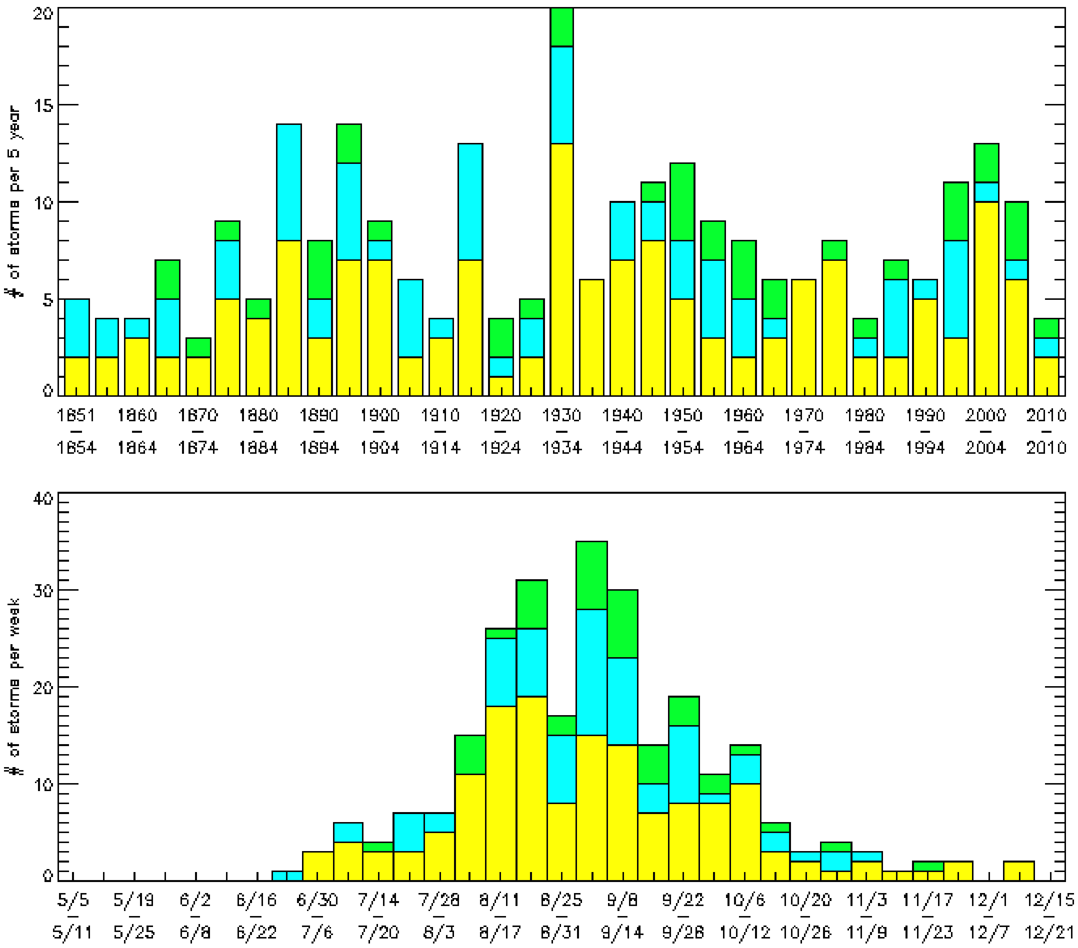

Figure 3.3 Occurrence of storms and hurricanes in the Eastern Caribbean between 1851 and 2010: tropical storms (yellow), hurricanes category 1-2 (blue) and hurricanes category 3-5 (green) (source: www.stormcarib.com). The number of storms per 5 years is given in the top panel, most of which occur from July through October.

3.1.2 Currents

No information is available on tidal and subtidal currents around St. Eustatius in general, and near the harbour area in particular. As an alternative, the available information in the literature on large-scale current patterns are briefly analysed and extrapolated this to the harbour area.

The subtidal currents are dominated by the Caribbean Current, transporting South Atlantic water through the Caribbean and into the Florida Current and the Gulf Stream. The Caribbean Sea is influenced by the dispersal of the freshwater from the Amazon and Orinoco Rivers, which is discharged into the tropical Atlantic and partly advected into the Caribbean Sea (Cherubin and Richardson, 2007). The eastern islands of the Lesser Antilles are influenced by the Atlantic Current, with large northward velocities. Most of the Atlantic Current that flows into the Caribbean Sea infiltrates through the Winward Antilles in the south, generating strong westward current velocities. Water also infiltrates through the Leeward Antilles in the North, but at much lower flow velocities. Large-scale eddies generate local eastward-directed flow velocities. Model simulations (Cherubin and Richardson, 2007) suggest that near St. Eustatius, the flow velocity on the westward side is fairly low (in the order of 10 cm/s). It has a persistent but weak northward component, but the east-west component is less clear. South of St. Eustatius, the Atlantic waters seems to be flowing into the Caribbean Sea, but North of St. Eustatius water is flowing from the Caribbean Sea into the Atlantic. In contrast, observed currents (Johns et al., 1999) display a much stronger westward current component than Cherubin and Richardson's model simulations. It is therefore concluded that the subtidal currents in the Caribbean Sea around St. Eustatius are low, in the order of 10 cm/s. The available literature is inconclusive whether the flow in the straits North and South of St. Eustatius are directed eastward or westward. On the eastward side of the island, near the Harbour, the flow is probably directed northward. The flow velocities close to St. Eustatius may be higher than in open sea due to local acceleration around the island, but may also be lower because of increased friction. A reasonable upper limit for the subtidal current velocity is therefore taken as 20 cm/s (approximately double the estimated currents at open sea), while 10 cm/s is taken as a most likely estimate; both are directed Northward.

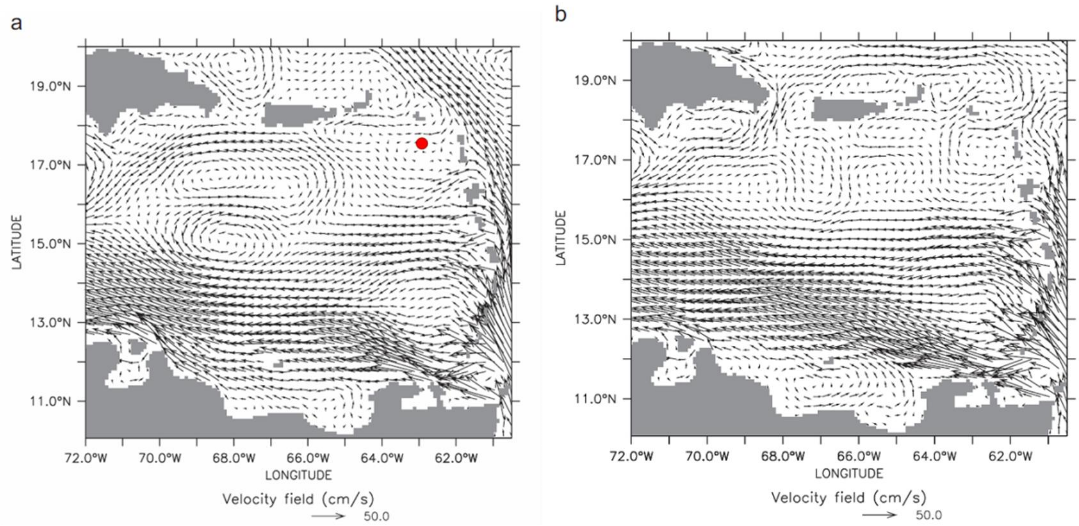

Figure 3.4 Modelled surface velocity in the Caribbean Sea in January-July (a) and August-December (b), from Cherubin and Richardson (2007).

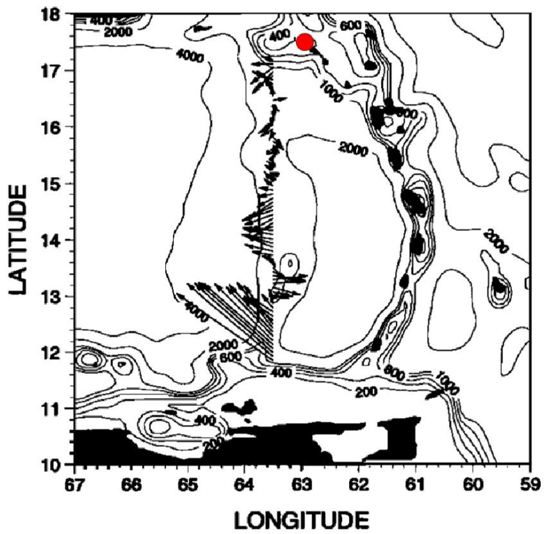

Figure 3.5 Surface velocity in the Eastern Caribbean, observed during 23 cruises carried out between 1984 and 1996 (Johns et al., 1999). The location of St. Eustatius is indicated with the red circle. The flow velocity in the southern part of the transect exceeds 1 m/s, while the flow velocity in the North is around 10 cm/s.

The Caribbean Sea has a microtidal range, frequently between 10 and 20 cm (Figure 3.6), and can be mixed semi-diurnal to mixed diurnal (Kjerve, 1981). Near St. Eustatius, the tide is predominantly diurnal because an amphidromic point of the semi-diurnal constituents exists west of the Leeward Antilles (Kjerve, 1981). No information could be found in scientific literature on the strength of the tidal currents. It seems unlikely that the low water level gradients generate strong tidal currents in a water depth as large as the Caribbean Sea.

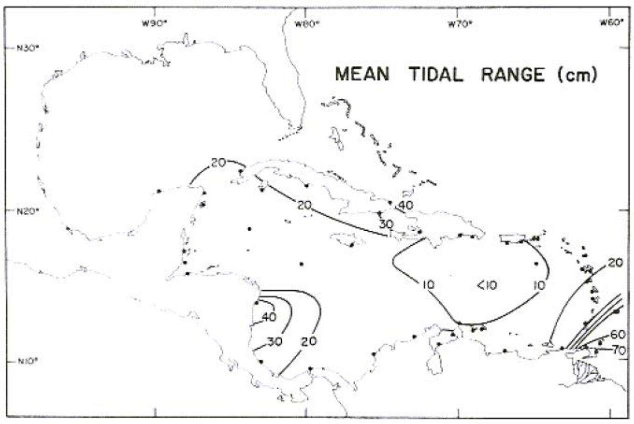

Figure 3.6 Mean Tidal range in the Caribbean Sea (Kjerve, 1981).

It therefore seems that both subtidal and tidal current velocities in the vicinity of St. Eustatius harbour are low. This is supported by mariner's manuals (i.e Sailing Directions, 2004), in which no warnings or notices to mariners are issued on currents. However, Kateman and Bos (2010) report that substantial currents can be generated during storms and by breaking swell waves. Normally these currents are from the south but during the winter storms ('brown seas') currents may be from the North. Storm-driven flow velocities may be 1 to 1.5 m/s (Kateman and Bos, 2010).

3.2 Sediment type and dredging activities

3.2.1 Soil description

A map of surface sediment is made available by Cees Laban (pers. comm.) while geotechnical studies have been reported by Haskoning (de Kant, 2011) and Geotron (Pachen, 2010). According to the surface sediment map, the dominant sediment type in the area to be dredged is fine sand (see Figure 3.7). A dominance of sand was also concluded by older studies reviewed by de Kant (2011), located 1.5 km north of the harbour:

- The offshore boreholes show a rather regular pattern of predominantly fine to medium fine sand strata; shell fragments present and locally imbedded with some gravel
- Thin layers of silt were encountered deep below the seabed
- Scattered traces of rock were encountered throughout the investigated area
- The geophysical reflectors imply that the volcanic bedrock slopes steeply down, starting from a depth of at least 25-30 m below chart datum at the coastline
- The investigation at the beach indicates that the upper layer of beach sand is underlain by rocky materials

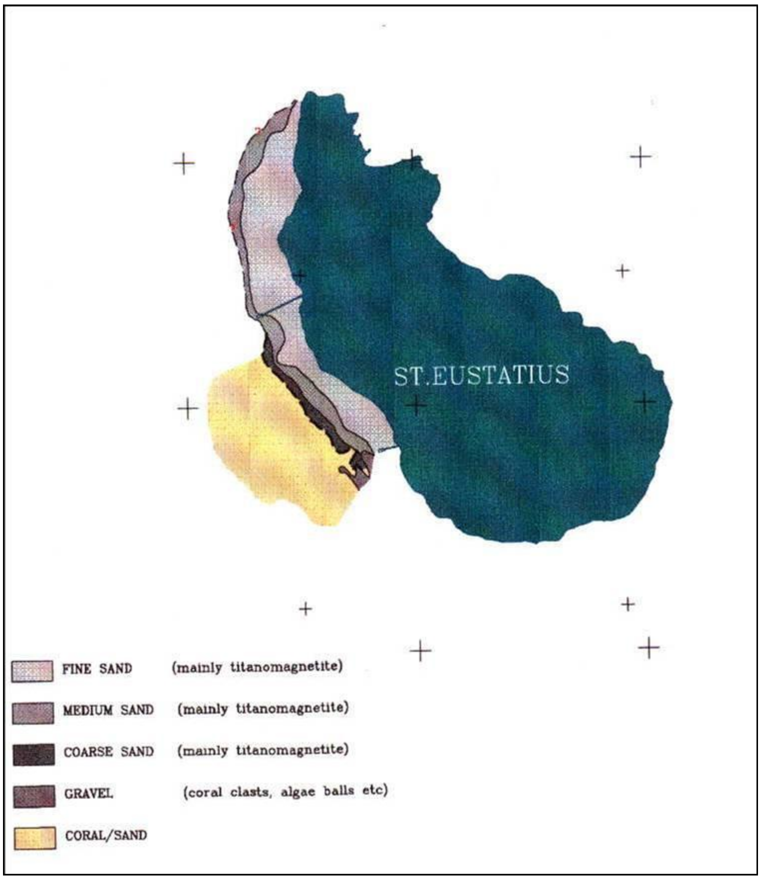

Figure 3.7 Sediment type in the St. Eustatiusharbour area (pers. communication C. Laban, Deltares).

In contrast, the Geotron corings reveal that the substrate is composed of a hard top layer (layer 1) overlying a softer and porous tuffaceous conglomerate (layer 2), which overlies sand (layer 3): see the location of all drillings in Figure 3.8 and a typical example in Figure 3.9 (Pachen, 2010). Layer 1 consists of a medium to hard crust, comprising a matrix of cemented volcanic ashes with interbedded pebbles, cobbles and boulders. In the top zone sometimes, a very porous hard igneous rock is present. This crust is very variable in thickness with a very variable cementation degree. In layer 2 a matrix of soft Calcium Carbonate, with embedded hard granite/basaltic/ andesite/dolerite gravels and pebbles, is determined. This layer is varying in thickness from 0.75 m till 3 meters. Possibly large size boulders, consisting of hard rock, are interbedded in the Calcium Carbonate matrix. Layer 3 consists primarily of sand and gravel.

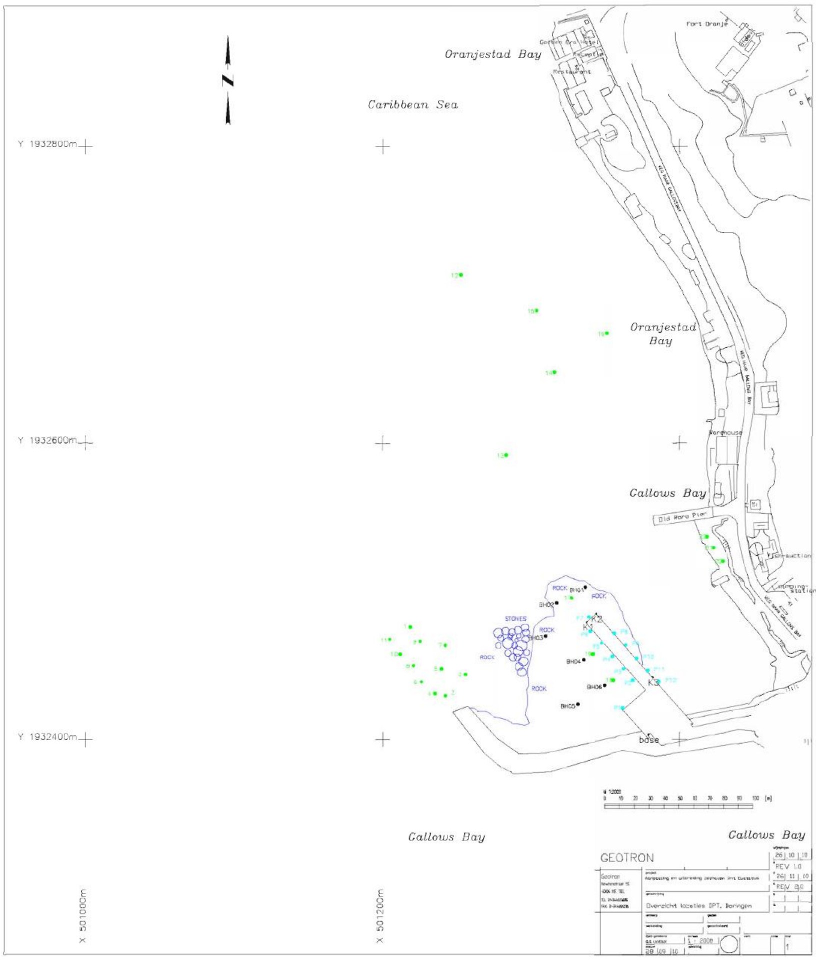

Figure 3.8   Location of Geotron corings (Pachen, 2010)

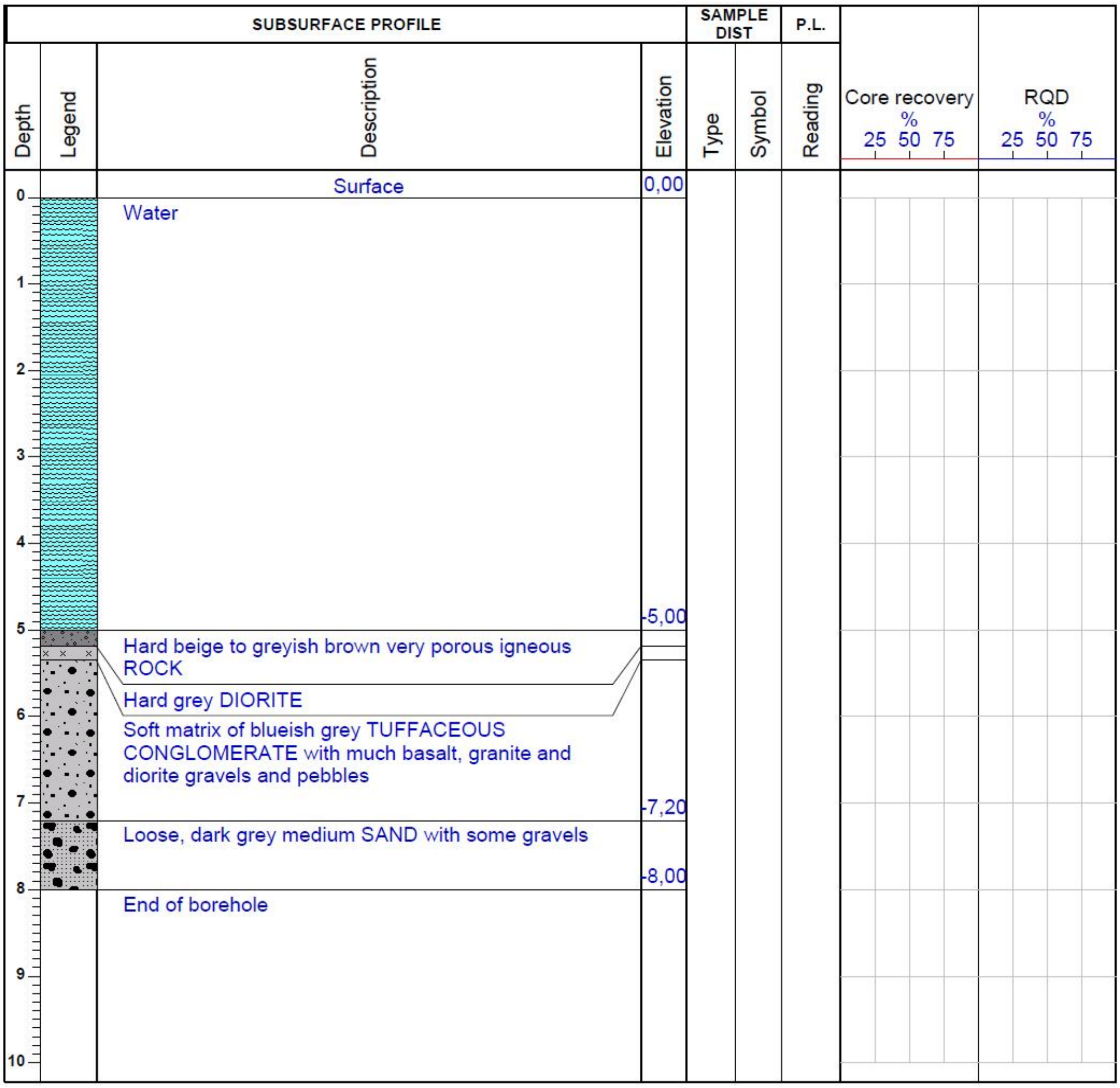

Figure 3.9 Sediment core number 1, from Pachen (2010).

These drillings logs and available literature can be interpreted as follows. The volcanic rock is approximately 30 m below the water surface, overlain by sand and gravel. This sand/gravel layer is overlain by a conglomerate of rock fragments, eroded from the rocky shores, mixed with the underlying sand. This mixture is cemented into a moderately hard conglomerate by calcium carbonates, which are abundantly available in a coral rich environment. Especially the top layer of several dm to half a meter is strongly cemented. The observed occurrence of igneous rocks, including diorite, in the top layer is remarkable. This layer must be large rocks eroded from the shore, which may have once been part of a matrix of finer sands and pebbles, all of which have been eroded away. The largest fragments remain and form a pavement over the more granular substrate.

In the available literature there is no reference to the existence of mud (silt or clay). It is unclear whether there is no mud, or there is little mud, or that the mud fraction has not been investigated. It is likely that the mud content is low (less than 5%), because (1) the site is too energetic (swell waves) for mud to deposit, (2) had mud deposits been large, then it would probably been mentioned in literature, and (3) there is no obvious source of mud. It is therefore assumed that the mud content is lower than 5%.

There is also no information on the amount of calcium carbonate. Some is present, probably resulting in cementing the sand. However, if present, erosion of calcium carbonates results in white clouds of considerable turbidity and very low settling velocity. Since no reference is made to extensive calcium carbonate deposits, it is assumed its presence to be insignificant.

3.2.2 Dredging method

The dredging procedure is described by Volker Construction International (2011). The turning basin of the harbour will be dredged to a level of – 6.5 m LWS. (-6.75 m LWS in case of hard rock bottom) using a trailer dredge. Dredge material will be discharged at the shoreline on the Southside of the breakwater (the larger triangular beach in Figure 2.1). The outlet pipe will be positioned on the present beach and harbour authorities will afterwards provide protection to keep dredge material in place. Sediment dredged in the old harbour will be disposed in the smaller beach immediately south of the old harbour (the smaller triangular beach in Figure 2.1). In case of boulders at the dredging area, the dredge will sink these boulders by dredging around the boulders. Although not expected, when solid rock bottom is in the dredge area a barge with crane and grabber will be mobilised to remove rock bottom in a later stage.

During the dredging of the turn basin a bubble screen of approximately 90 m will be installed near the disposal area in order to limit siltation of the reef. A rubber hose ¾” will be placed on sea bottom and with a compressor the perforated hose will form a bubble screen. The bubble screen creates a vertical current, which will reduce horizontal transport of silt particles.

3.3 Effects of dredging

3.3.1 Short term

The removal of the hard top layer will result in a substantial spill of sediments during dredging. In order to assess the effect on dispersal in the water column, it is assumed that 25% of the dredged material is brought in suspension. This is a considerable percentage: during many dredging activities typically 5 to 10% of the material is brought in suspension. Since 10.000 m^3 of sediments is dredged, up to 2.500 m^3 of sediment may be brought in suspension. Under hydrodynamically calm conditions, most sand and gravel will immediately settle on the bed, while only very fine sand and mud (silts and clay) will be transported by the ambient current. The hydrodynamic analysis reveals that under non-storm conditions, currents in the area are probably very weak, and not able to resuspend sand or gravel. Silt and clay dispersed into the water column will be transported with the ambient currents at a rate up to 0.2 m/s, and probably northward. An important shortage in available information is that it is unknown what the mud content in the sediment is. If there is no mud, the direct effects of dredging are low. A likely upper limit of the mud content is 5%. If more mud had been present in the sediment, it would probably been given attention in the various site investigations. A mud percentage up to 5% implies that up to 5% of 2500 m3, or up to 125 m^3 (approximately equal to 2 10^5 kg) of fine sediment, is brought in suspension. With a flow velocity up to 0.2 m/s, turbulence levels are insufficient to keep even the majority of the fines in suspension. Flocculated mud and silt will settle with a speed of 1 mm/s or larger and therefore deposit within 2 hours in water 7 m deep. With an ambient current up to 0.2 m/s, sediment will be deposited within 1400 m of the dredging site (and probably North of the harbour). Only the finest fraction will be dispersed further away, but this fraction is so fine that it will not settle elsewhere and will rapidly dilute with the surrounding seawater.

This situation is different during storm conditions, when sediment can be transported over much longer time periods because the flow- and wave-induced turbulence levels are higher (keeping sediments in suspension), and the velocity at which particles are transported away is higher. From December to April, the Florida cold fronts result in a strong north to north-western swell, generating pronounced southward currents. When dredging is done during these conditions, sediment in the dredge area may remain in suspension and transported southward, beyond the windbreaker. The same applies to hurricanes, although the direction of storm-driven currents during hurricanes may be southward as well as northward. Probably, however, dredging is not possible during either the cold front swells (‘brown seas’) or during hurricanes / tropical storms.

3.3.2 Long term

The deepening (not sediment disposal) may potentially have negative effects over longer timescales, and is discussed below. Negative aspects may be:

- Wave penetration increases, leading to changes in long-shore transport, and therefore a further exacerbation of coastal erosion
- Increased vessel traffic causing more waves and anchoring activity, potentially leading to more erosion
- Dredging works exposing layers softer substrate, leading to more erosion and turbidity

3.3.2.1 Wave penetration

A deepening of the foreshore general leads to higher waves on the coastline, and therefore concerns exist that the deepening may lead to more erosion. This is visualized in Figure 3.10. Waves affecting the coastline of the inner coastline are strongly limited by the jetties of the old and the new harbour, leaving approximately one quadrant of wave directions affecting the harbour. Therefore only western waves affect the northern part of the coastline (green), while only north-western waves affect the southern coastline (purple). When these line overlap with dredging areas, deepening may affect coastline erosion. This brief visualization indicates that the old harbour deepening more strongly influences the coastline than the new harbour deepening. Especially since waves traversing the deepened new harbour area subsequently propagate over undisturbed bed topography. This latter also applies to the effect of the old harbour deepening on the southern part of the coastline. Therefore the northern part of the inner harbour coastline is most strongly influenced by the deepening, during western to north-western waves. These conditions occur during the ‘browns seas’, leading to considerable wave heights in December to April. This includes the ruins just south of the harbour: while shallow water (1.8 m or less) used to exist seaward of the ruins, the water depth will become 3.25 m immediately seawards of the ruins after the deepening.

Effect of deepening on the coastline north of the old harbour and south of the windbreaker is considered to be negligible, since the deepened areas are sheltered by the jetties.

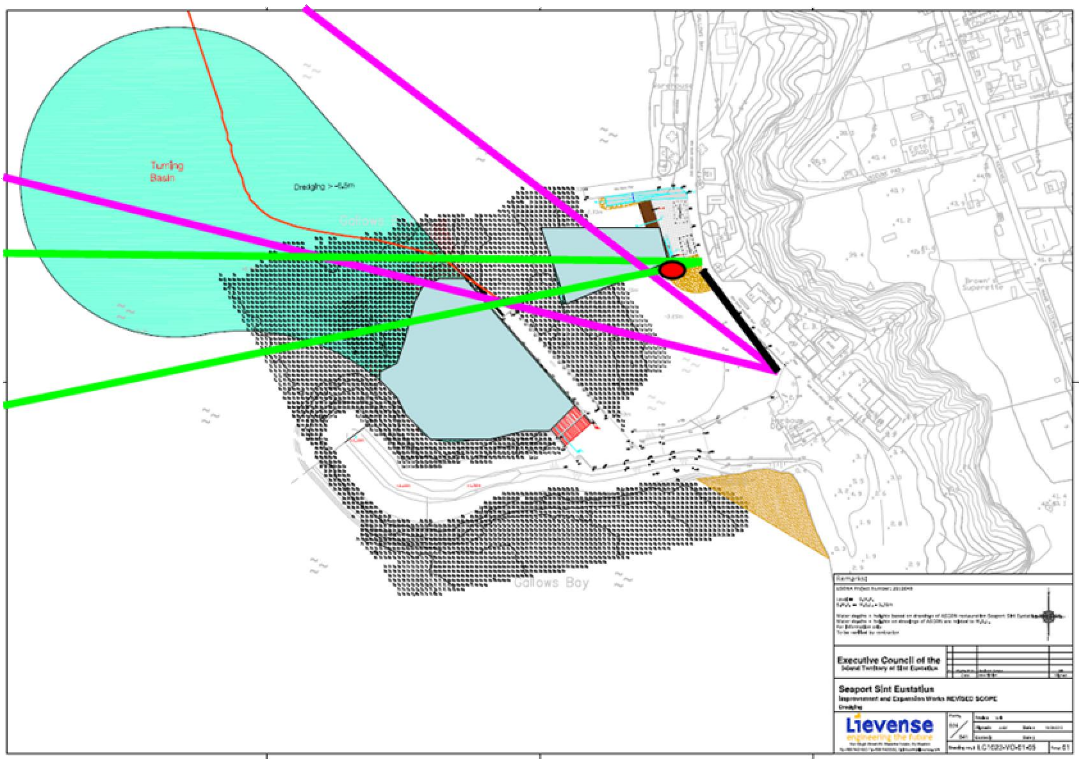

Figure 3.10 Map of dredging locations (light blue) and lines where the coastline in the inner harbour area coastline (in black) may be affected. The purple line indicates wave directions affecting the southern part of this coastline, the green line the wave direction affecting the northern coastline. The black/red circle denotes the position of ruins just south of the harbour.

3.3.2.2 *Ship anchoring*

Increased ship anchoring will probably lead to slightly increased resuspension of bed sediment, depending on the type of bed sediment. If the bed consists of sand and gravel, then this is probably unimportant. Should the bed consist of mud, then ship anchoring substantially increases turbidity. At present, the mud fraction is probably low (otherwise the water would already be turbid), but dredging could results in more fine sediment on the bed (see next section).

3.3.2.3 *Modified substrate*

The baseline data available suggest that the dredging works remove a hard top layer from a softer underlying layer. The deepened area is exposed to the north-eastern swell occurring 1-2 times per month in December to April (the ‘brown seas’). At a water depth of 7 m and offshore waves 3-4 m high, waves will break near the deepened area, resulting in high wave-induced bed shear stresses eroding all uncemented sediment finer than gravel. During these conditions, currents are largely directed southward. If the sediment in the softer layer consists of fine sands, this sediment will be remobilized during the north-eastern swell in December to April (the ‘brown seas’) and transported southward.

3.3.3 Dredge disposal

3.3.3.1 Northern disposal site

Approximately 3000 m^3 of sediment will be deposited in the northern disposal site, just south of the old harbour. The wave height in this area is probably low, and most therefore coarse sand and gravel will remain in place. Fine sands will be transported southward during north-western swell. Since there are no mechanisms transporting sediment back northward, after a certain period this sediment will be distributed over the entire inner harbour coastline (red line in Figure 3.10). Due to the sheltered location, offshore transport of this material will be limited, even during hurricanes, and the sediment remains trapped in the inner harbour area. However, uncontained, the sediment will not remain on the disposal site for long, given the high frequency of storm related seas in St. Eustatius.

3.3.3.2 Southern disposal site

During disposal, sediment is contained near the disposal site using a bubble screen. Combined with the expected low fraction of mud, loss of sediments will be low during disposal itself. However, if the sediment is not contained it may be eroded during storms. The dominant wave direction during the winter storms is north to northeast, for which the disposal site is fairly well sheltered. During hurricanes, high swell waves and local waves are substantially high throughout the coastline, which in combination with a water level setup typical during such events, are likely able to erode the deposited sand. This material will disperse to the west, south, and offshore. Without more detailed information, the rate of erosion of the planned deposit cannot be predicted. The contribution of this deposit to nearshore turbidity during a hurricane can also not be predicted.

4 Marine environment of St. Eustatius

In order to assess the potential impact of the planned activities and related pressures a description is given of the marine environment of St. Eustatius, including the vulnerability and respective resilience of a number of habitats and species towards these pressures. The description is based on a quick scan of the literature review, combined with personal observations from 2010, satellite imaging and expert judgement.

4.1 General overview

The entire coast of St. Eustatius is designated as St. Eustatius National Marine Park, down to the 30 m water depth contour. It is not allowed to use anchors within this Marine Park. Vessels and yachts can moor at one of the 12 designated mooring buoys present in the bay. Within the Marine Park, there are two Marine Reserves; the Northern Marine Reserve and Southern Marine Reserve, with very strict regulations for any activity that may impact their ecology.

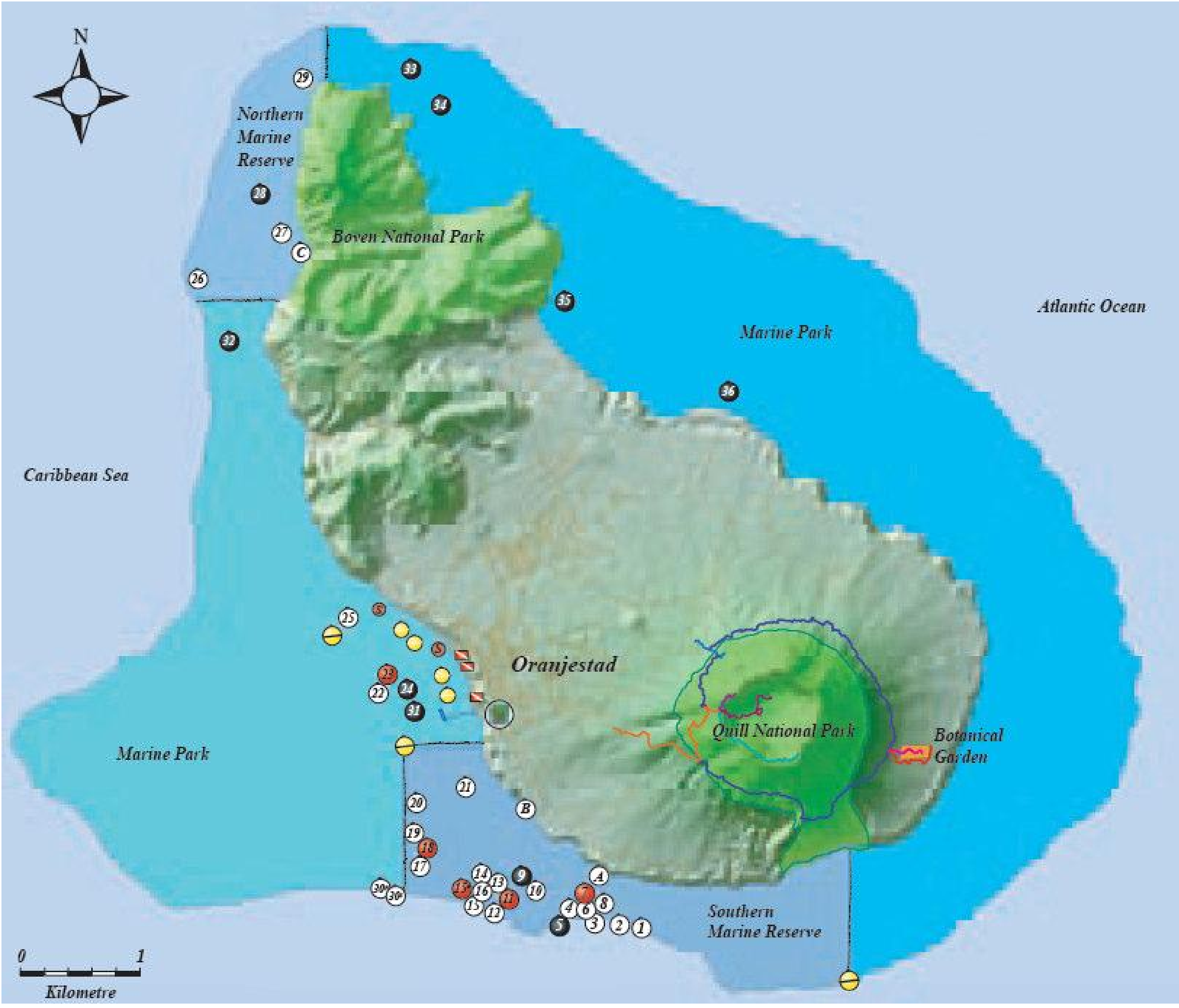

Figure 4.1 Map of St. Eustatius Marine Park and marine reserves.

The habitats for underwater life in the Marina Parks can be divided into

- Coral reefs
- Sand possibly covered with rocks/rubble (benthic ecosystem)
- Seagrass

Figure 4.2 shows the areas around St. Eustatius for habitat types, according to a very recent survey (STENAPA, via Kateman and Bos, 2010). In the Orange Bay mostly sand with sea grass is present. Coral reefs are present all around St. Eustatius in deeper areas and near the coast in the north of the island.

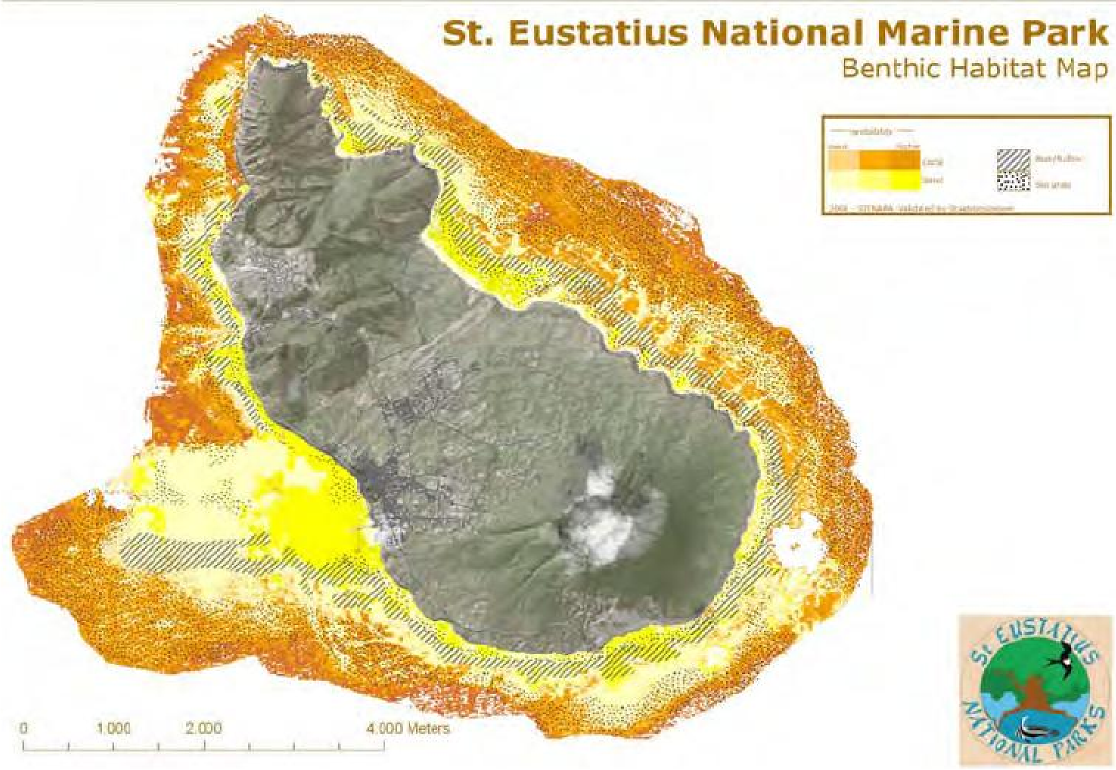

Figure 4.2 Habitat map of St. Eustatius (source: STENAPA via Kateman and Bos, 2010)

Based on satellite imaging, bathymetric data and Figure 4.2, a second habitat map was developed (Figure 4.3) from which a rough calculation was made on the total surface per habitat per depth category (Table 4.1). The habitats <10 m^2 could not be estimated due to lack of data.

Table 4.1 total area per habitat in St. Eustatius per depth category

Habitat	10-25m	25-35m	>35	Total estimate
Sand	270 ha	38 ha		308 ha
Seagrass	520 ha	15 ha	500 ha	1035 ha
Coral	600 ha	170 ha	300 ha	1070 ha
Rock/Rubble	540 ha			540 ha

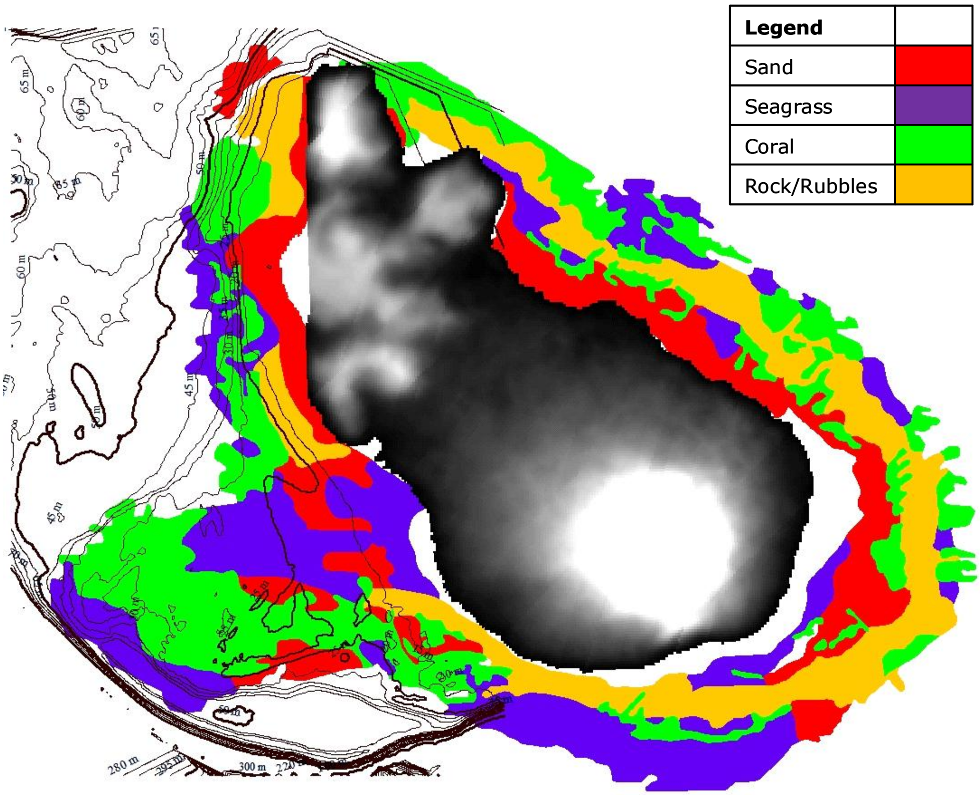

Figure 4.3 Habitat map of St. Eustatius based upon a satellite image and Figure 4.2 (IMARES, 2010)

4.2 Coral reefs

4.2.1 General

Coral reefs are among the most diverse ecosystems on earth. Relationships between the living and non-living components are complex and often poorly understood. Coral colonies play a primary role in the construction and maintenance of reefs, as well as providing support and shelter for the many other organisms that inhabit coral reefs. Globally reefs are experiencing unprecedented anthropogenic impacts from sea water warming and acidification (Meesters & Bak 1993, Anthony et al. 2011), sedimentation (Bak 1978, Cortes and Risk 1985, Rogers 1990), eutrophication (Fishelson 1973, Tomascik and Sander 1985) and resource exploitation such as fishing (Munro 1983, McClanahan 1987, Hughes 1994).

Sedimentation is one of the most important factors threatening reefs globally. Grigg and Dollar (1990), in a review of natural and anthropogenic disturbances on coral reefs, state: “The impact of increased sedimentation is probably the most common and serious anthropogenic influence on coral reefs.” Increased sedimentation results primarily from dredging and runoff.

4.2.2 St. Eustatius

The Windward Group does not seem to have reef -development comparable with the reefs of the Leeward Group. Major factors restricting coral reef development are the flat, sandy character of extensive parts of the seafloor and the absence of steep slopes (Goreau & Wells, 1967). Also, the Windward Group is situated in the Caribbean hurricane belt. Studies on the mechanical effect of hurricanes in the Caribbean have shown their destructive force to be catastrophic to coral reefs (Stoddard, 1963; Glynn et al., 1964). These effects seem, however, to be restricted to rather shallow water. Stoddard (1963) observed the coral survival to be much better even at depths as shallow as 7-13 m. He also noted that *Acropora cervicornis* was the least resistant coral. J. van der Land (pers. comm.) mentioned *A. cervicornis* at depths of less than 15 m around St. Eustatius. This shows that hurricane effects do not prevent growth of the most sensitive coral at these depths."

There are a variety of reef types on St. Eustatius, from shallow sloping reefs to patch reefs through volcanic boulders of various sizes to spur and groove type reefs with sandy channels divided by lava fingers. Each of these offer hard substrate for coral and other animals to settle on, which in turn attracts fish and an abundance of other invertebrates (MacRae& Esteban, 2007).

In deeper areas, the coral communities are dominated by plate corals (*Agaricia sp.),* soft corals such as Seafans and Wire Corals (*Ellisella sp.).* The main hard corals on shallower reefs include Mustard Hill Coral (*Porites astreoides*), Brain coral (*Diploria sp.),* various forms of Star coral (*Montastrea sp.),* Flower Coral (*Eusmilia fastiagata*), Maze Coral (*Meandrina meandrites*), Pillar Coral (*Dendrogyra cylindrica*) and the blade form of Fire Coral (*Millepora complanata*). Other coral species often found include Seafans, Seaplumes, gorgonians and Black coral (*Antipathes sp.)* at depths in excess of 20 m, particularly at the drop off (MacRae & Esteban, 2007). South of the harbour, at Crookes castle, the following coral species are reported by STENAPA.

- *Porites porites* (Finger)
- *Acropora palmata* (Elkhorn)
- *Millipora complanata* (Fire)
- *Millipora alcicornis* (Fire)
- *Meandrina meandrites* (Maze)
- *Porites astreoides* (Mustard)
- *Diploriasp*. (Brain)
- *Sidastrea radians* (Star)
- *Agaracia lamarck*i (Sheet)
- *Montastrea faveolata* (Great star)

The total coral reef area in St. Eustatius is presented in table 1. Few corals are found deeper than 25 m.

MacRae & Esteban (2007) report that reef health is generally excellent based a 2002 AGGRA survey of 30 Caribbean sites. It is stated that the reef is in good health with diverse fish population and no signs of pollution. There is very little mechanical damage to coral reefs due to two factors, first that reefs are fairly deep and beyond the depth that vessels (propellers/hulls) would damage corals, second that all non-resident divers must dive with a dive guide from a local dive centre.

Although it is reported that the reef is in a good condition in general terms, two aspects should be mentioned. There is significant sedimentation in the Marine Park due to erosion of cliffs and hillsides during heavy rainfall (a 'plume' is often visible around the island after heavy rainstorms) but not much sediment is observed on corals due to the fact that it is dispersed by the time it reaches most of the coral reef (depths of >10m). The major source of land based pollution is from the Smith's Gut Landfill Site near Zeelandia Beach on the Atlantic coast.

Secondly, in 2005 there was a major coral bleaching event. Two sites in the Southern Marine Reserve of the Marine Park (Barracuda Reef at 23m depth and Mushroom Garden at 16m depth) which are monitored on an annual basis show significant bleaching impact. Barracuda Reef showed a loss of hard and soft coral due to bleaching of 34.8% in 2005 and 2006. Mushroom Garden lost hard and soft corals up to a total 78.6 % in the same years (MacRae & Esteban, 2007 MacRae & Esteban (2007) report that reef health is generally excellent based a 2002 AGGRA survey of 30 Caribbean sites. It is stated that the reef is in good health with diverse fish population and no signs of pollution. There is very little mechanical damage to coral reefs due to two factors, first that reefs are fairly deep and beyond the depth that vessels (propellers/hulls) would damage corals, second that all non-resident divers must dive with a dive guide from a local dive centre.

4.2.3 Threats to coral reefs

4.2.3.1 Downward sedimentation

Background levels of sedimentation on reefs that are not influenced by human activities are between 1 and 10 mg per cm^2 per day (Rogers, 1990). Rogers suggests that chronic sedimentation rates above 10 mg per cm^2 per day are “high”. In Kenya sedimentation values of 1.35 and 4.25 $mgcm^{-2}d^{-1}$ did not lead to differences in coral cover (McClanahan and Obura 1997). Sudden exposure to heavy sedimentation may result in burying of corals, expulsion of the symbiotic algae from the coral polyps (”bleaching”), and subsequent death. Other effects of increased sedimentation (varying from 200 to 800 mg per cm^2) include: no effect, reduced growth, reduced calcification (33%), decrease in net production, and increase in respiration. Short-term increases, which can be measured by traps, are generally less deleterious to corals than chronic increases (Dodge and Vaisny, 1977; Bak, 1978; Tomascik and Sander, 1985). However, burial under a heavy sediment load will lead to coral death within a few days. Indirect effects may include reduced recruitment of corals if hard bottom is covered by sediment.

4.2.3.2 Suspended Particulate Matter (SPM)

SPM concentrations represent an instantaneous measure of the concentration of particles suspended in the water column, whereas sediment trap data measure the total downward flux of suspended particles.

SPM is a better descriptor of long-term sediment effects on coral reefs. For coral reefs the following concentrations have been described as low, medium and high concentration (Meesters et al. 1998).

	low		Medium		High	
SPM ($mg.l^{-1}$)	0	2.5	1.5	6.0	4.0	7.0
Sediment in traps ($mgcm^{-2}d^{-1}$)	1	10			200	800

4.2.3.3 Quantification of sediment load

Traditionally, sediment traps have been used to quantify sedimentation, however, this technique suffers from high spatial and temporal variation of trap data (Pastorok and Bilyard, 1985) as well as additional variation introduced through the use of different trap designs (Bloesch and Burns, 1980). Also, trap height above the bottom is also critical, since bottom sediment is resuspended in different concentrations to different heights at a fixed wave regime (Meesters, 1995).

4.2.3.4 *Accumulation of effects*

Little is known about the cumulative effects of several stressors on corals. Sediment on coral tissues can be removed by ciliary action, however, this requests extra energy from the polyp (e.g. effects on regeneration of damage (Meesters et al. 1992). If energy availability is already reduced because of reduced light levels from higher loads of suspended sediment, corals are likely to suffer additional mortality from sediment settling on their tissues. Another factor that should be taken into account is the effect of bleaching. During the end of the summer sea water temperatures are high and this may lead to bleaching of corals. In 2010 there was a severe bleaching event and corals in Bonaire were still recovering when surveyed in July 2011. Unfortunately little is known of the corals in St. Eustatius. This means that their resilience is likely to be low and additional stress may lead to rapid mortality of these corals. Other factors that may reduce the ability of corals to cope with increased sediment loads/reduced light levels are high nutrient levels, high UV levels.

4.2.3.5 *Effects on different species*

Coral species respond differently to heavy sedimentation and some are more efficient in rejecting sediment than others. Bak and Elgershuizen (1976) found that *Acropora palmata, A. cervicornis, Porites astreoides* and *Agaricia agaricites* were the least efficient and *Colpophyllia natans, Diploria strigosa* and *Madracis mirabilis* were among the most efficient. Rogers (1990) in a review concludes:

1) Different species have different capabilities of removing sediment or surviving at lower light levels
2) The coral’s ability to remove sediment depends on the amount and type of sediment, which covers the coral colony
3) Sediment rejection is a function of morphology, orientation and behaviour of a coral colony

A very crude scheme based on expert knowledge, but not yet verified by literature review.

Scientific name	**Common name**	**Estimated sensitivity to short increased sediment load**	**Estimated sensitivity to burial**	**Estimated sensitivity to long-term increased SPM**
Porites porites	Club tip finger coral	Low	High	Medium
Acropora palmata	Elkhorn coral	Low	High	High
Millipora complanata	Bladed fire coral	Low	High	High
Millipora alcicornis	Fire coral	Low	High	High
Meandrina meandrites	Maze coral	Low	Medium	Medium
Porites astreoides	Mustardhill coral	Low	Medium	Medium
Diploria spp.	Brain corals	Low	High	High
Sidastrea radians	lesser starlet coral	Low	Medium	Medium
Agaracia lamarcki	Lamarck's sheet coral	Medium	High	High
Montastrea faveolata	Mountainous star coral	Medium	High	High

4.3 Seagrasses

4.3.1 General

Seagrasses are flowering marine plants with a global distribution in shallow (coastal) waters. They often form dense meadows providing important ecological functions and services. They provide critical habitats and nursery and feeding grounds for fish and shellfish (including species of economic importance) and flora and fauna communities including organisms such as green sea turtles, dugongs and manatees, and many associated organisms, several of which charismatic and/or endangered species that are important to conservation. Seagrasses perform important functions in filtering coastal waters, dissipating wave energy, stabilizing sediments, capturing suspended particles and nutrient re-cycling. They have furthermore an important ecological linkage function with nearby coastal systems such as mangroves and coral reefs in tropical waters.

4.3.2 St. Eustatius seagrasses

Seagrass species found in the coastal waters of St. Eustatius include *Thalassiate studinum, Syringodium filiforme*, *Halophila decipiens* and *Halodule wrightii.* St. Eustatius seagrass ecosystems are dominated by the first three species. Seagrass depth distribution is from the lower intertidal zone up to about 35 m depth (STENAPA, 2007; visual observations). The total seagrass coverage in the coastal waters is approximately 1000 ha (< 25 m: 500 ha; > 25 m: 500 ha). *T. testudinum* and *S. filiforme* are confined to shallow areas up to about 15 m. *H. decipiens* is distributed over the entire depth gradient. Deeper seagrass meadows consist almost entirely of *H. decipiens*. Conch, Flying Gurnards and turtles are examples of species at St. Eustatius, which depend for their wellbeing on seagrass beds.

4.3.3 Threats

The most important threats to seagrasses at St. Eustatius are damages from boat anchors, pollution, dredging, coastal engineering and hurricanes. Since the early 1980s significant decline in seagrass area is reported due to anchoring from tankers (especially in the deeper areas from 20-30 m), breakwater construction, pipeline deployment and hurricanes (especially in the late 1990s; STENAPA, 2007).

Main potential impacts on seagrasses from dredging include physical removal and/or burial of vegetation and effects of increased turbidity and sedimentation caused by the dredging process itself, as well as the transport and disposal processes. Secondary effects of dredging such as changes in current patterns and velocities and wave conditions may alter sedimentation and erosion processes. The critical threshold for turbidity and sedimentation, as well as the duration that seagrasses can survive periods of high turbidity or excessive sedimentation, vary greatly among species. Other potential threats to seagrasses related to dredging include pollutant contamination, increased concentrations of nutrients and organic matter and reduced oxygen levels (see review by Erftemeijer and Lewis III, 2006; Cabaço et al., 2008).

Smaller fast growing species such as *Halophila* sp. or *Halodule* sp. do not endure long once environmental conditions are beyond that to which they can adapt, but they tend to recolonize more quickly following an impact. Larger seagrass species such as *Thalassia* sp. tend to have greater stored reserves that can be mobilised to sustain the plant temporarily during unfavourable periods. However, once lost, recolonization of these species is unlikely or at best slow. Recovery of subtidal seagrass meadows from large-scale disturbance has been shown to take 2–5 years. Often, denuded areas may not recover for many decades and when water quality conditions do not return to their original state, recovery of subtidal seagrass may not occur at all (see Erftemeijer and Lewis III, 2006 and references therein).

From the reviews by Erftemeijer and Lewis III (2006) and Cabaço et al. (2008) the following critical threshold are estimated for the seagrass species of St. Eustatius (Table 4.2 and Table 4.3). Light availability below the given values will result in degradation. In case of (increased) leaf epiphyte loadings and sediment deposition on the leaf surface, light requirements go up. Depending on the intensity and duration of the disturbance, the period that the plants can sustain lower light levels may be different. The same holds for recovery time. The values given for burial levels lead to approximately 50% mortality, from which recovery is expected to take place (if environmental conditions do so allow). Higher burial levels will lead to increased mortality coinciding with smaller chances for and slower recovery. *H. decipiens* may be the exception to this rule.

Table 4.2 Critical light requirements for 4 species of seagrass , including estimated survival and recovery time. Based on Erftemeijer and Lewis III (2006) and Cabaço et al. (2008).

species	Light requirements (PAR) of SI	Survival (months)	Recovery time
T. testudinum	15-25%	Up to 11	Up to years
H. wrightii	15-30%	Up to 9	
S. filiforme	20-30 %		Up to years
H. decipiens	5%	Less than 1	fast

Table 4.3 Critical burial levels for 4 species of seagrass , including estimated survival and recovery time. Based on Erftemeijer and Lewis III (2006) and Cabaço et al. (2008).

species	Burial (cm)	Survival	Recovery time
T. testudinum	5	50 %	Slow
H. wrightii	2-4	50%	Medium
S. filiforme	3	50%	Slow-medium
H. decipiens	0-2	0-50%	fast

4.4 Sand/rubble habitat

Little is known about the sandy habitats between the shores of St. Eustatius and the coral reefs. The habitat is home to be home to various animals and plant, including crustaceans, worms and fish. Marine plants include weeds, seagrasses (see separate section) and weeds. The total area of sand and rubble habitat in St. Eustatius is approximately 850 ha (see Table 4.1).

Threats are habitat removal, habitat modification (grain size) and coverage with algae.

4.5 Marine mammals

4.5.1 The cetacean fauna in nearby St. Eustatius waters

At least 33 native species of marine mammals have been documented from the Wider Caribbean Region (WCR). For many of these species, the waters of the region serve as primary habitat for critical activities that include feeding, mating and calving. Debrot et al. (in review) compiled 84 marine mammal records for the waters of the windward Dutch Caribbean islands. A total of eight distinct species are documented, six of which are cetaceans. In comparison to the leeward Dutch islands (Aruba, Curaçao and Bonaire), documented strandings were few. Results suggest that whereas beaked whales and Bryde's whale are more common around the leeward Dutch islands, humpback whales are more common around the windward Dutch islands. However, of these eight species, up to now only three species can be confirmed for St. Eustatius waters. These are: Humpback whale, bottlenose dolphins and spinner dolphins. All three of these regularly visit shallow coastal waters and could potentially be affected by the project. So far all records of humpback whale are for the first two quarters of the year. Bottlenose and spinner dolphins likely occur year-round (Debrot et al. in review).

4.5.2 Threats to marine mammals

4.5.2.1 Underwater noise

Marine mammals use sound for critical life functions and have well developed hearing capability. They are very sensitive to submarine sound. A recent review sketches the wide extent of anthropogenic noise in the marine environment today (Hildebrand 2009). Simple noise caused by commercial shipping can seriously impair possibilities for communication in endangered species (Clark et al. 2009), while the noise from outboard motors can interfere with communication in dolphins (Jensen et al. 2009).

Sounds caused by sonar, as often deployed during military exercises and operations can even be very dangerous and even deadly. The same is true for other forms of sound such as caused by underwater munitions detonations (Bree and Kristensen 1974). Human disturbance through sound can also lead to chronic stress, which influences animal’s health (Wright et al. 2009). Deep diving beaked whales are particularly vulnerable (Wright et al. 2009). Therefore, Hatch and Fristrup (2009) stress the need for sound management in marine protected areas.

4.5.2.2 General vessel strike risk

Vessels strikes are known to be a large and growing threat to marine mammals worldwide. This is especially acute in shipping lanes, as worldwide more than 50% of shipping density occurs in about 2% of the ocean surface (Leaper and Panigada 2011).The Caribbean is one of the intensively used areas and will become even more so after the construction to double the Panama Canal is completed. Modern shipping involves large and large ships that move at ever increasing speeds. These form a great danger to marine mammals. In this large whale species are particularly vulnerable and especially animals and calves (Richardson et al. 2011). Today ship strikes have even become one of the principal sources of mortality for fin whales in the Mediterranean (Panigada et al. 2011). To prevent or reduce the risks of ship strikes, it is necessary to direct traffic to areas where the chance of ship strikes is lower, to have ships travel at lower speed in sensitive areas, or for them to use special radar to aid in early detection.

5 Archeology of St. Eustatius

St. Eustatius was an important centre of trade within the region during the 18th century, during which era it was known as the “Golden Rock”. As a consequence, St. Eustatius is covered with numerous ruins and remains of this period. The island boasts some 200 terrestrial sites and 200 shipwreck sites (Stelten 2009). St. Eustatius was also inhabited by man during prehistoric times. Some of the most extensive and impressive prehistoric archaeological research for the Dutch Caribbean has been done inland on the “Cultuurvlakte” (Versteeg and Schinkel 1992). Near the relevant locations of the harbour extension, several key monuments and historical sites are mentioned in the Royal Haskoningreport (Kateman and Bos 2010). They refer to pre-historical Indian settlements as well as remains of the colonial era. The following historical monuments are indicated on the map in Figure 5.1. In addition, the sea bottom in the vicinity of the harbour of Oranjestad is known to be thickly spread with historical artefacts. Test excavations by Nagelkerken in 1990 and 1991 at 40 small drilled hole sites in the harbour area uncovered 316 historical metal artefacts, as well as pottery artefacts. At least two more detailed studies have been conducted on the collected material (Nagelkerken 2000, Stelten 2009).

The main concentration of historical sites along the shore of Orange Bay (Fig 5.1) are:

- South of St. Eustatius Harbour: Crook’s Castle and The Factory
- Lower Town: Old warehouses, Submerged wall
- Near Smoke Alley: Fort Royal, Water fort, Leper colony, Cemeteries.

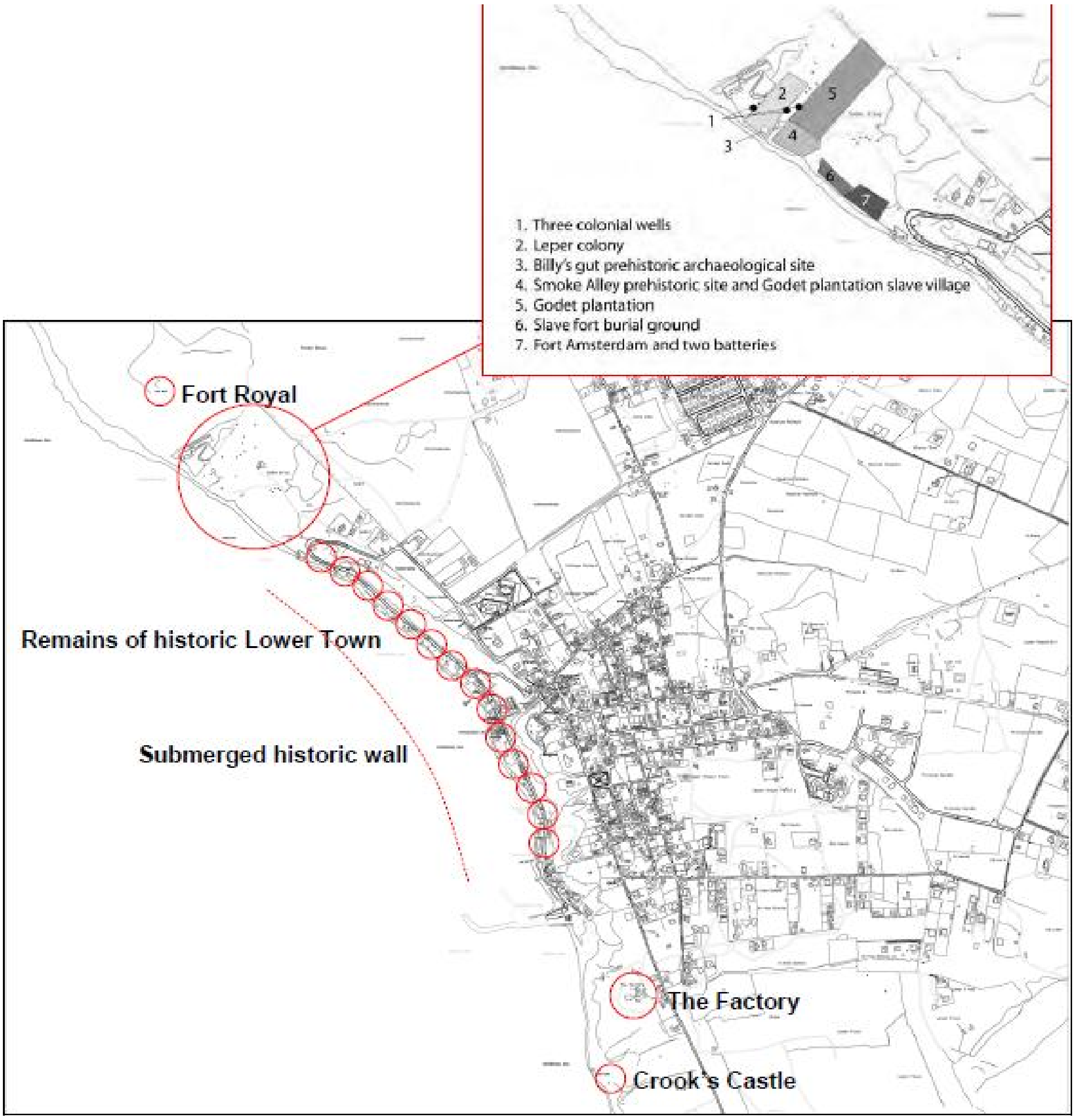

Figure 5.1 Locations of key monument in the relevant locations for this project. Historic locations near Smoke Alley are given more in detail. [source: Monument Foundation, St. Eustatius Historical Foundation museum, Domeinbeheer]

The potential effect of this project on the historical and archaeological sites are two-fold. One is potential damage by directly dredging and damaging an archaeological site or historical wreck that was not known to be present at the construction site and the second is potential damage due to long-term effects caused by altered current, wave or sedimentation patterns, which may affect effects on coastal erosion.

6 Impact Assessment

The deepening of the harbour may cause direct impact via the construction works and related pressures, and long term impact via the activities and pressures resulting from the new situation (future use and deposited material).

6.1 Direct impact

6.1.1 Dredging activities and related sedimentation

The tidal and residual currents around St. Eustatius are weak, and estimated to be up to 20 cm/s. Near the harbour area, the residual flow is probably dominantly north. The wave height is low throughout the larger part of the year, except during storms and hurricanes. From December to April cold fronts in Florida generate a swell from the north to northeast. These events occur once or twice a month, last for a day to a week, and generate swell waves 3 to 5 m high.

The marine substrate in the harbour area consists of a hard substratum overlying a more loosely packed conglomerate including sand and pebbles. This hard substratum consists of large rock fragments and cemented conglomerate. Removing this hard layer makes the underlying softer material available for erosion, especially since the deepened area is exposed to the winter swells and has a water depth where the swells may break (and hence lead to high near-bed shear stresses). The risk for increased levels of sediment is probably small, but depends on the fine silt content of the sediment to be exposed. This however is unknown at this moment.

During the dredging works, the sediment spill is expected to be limited. It is assumed dredging to be executed during calm conditions: during considerable swell the alongshore transport of the sediment spill could be substantially more. Sediment will enter the water column during dredging, but due to the low ambient currents sand will likely immediately settle from suspension. If present, silt and flocculated mud will be transported 1-2 km northward. Unflocculated mud can be expected to mix with ambient currents within days, leading to only limited increase in turbidity. Storage of dredged sediment occurs in the sheltered inner harbour and south of the breakwater. Little dispersion is expected due to the placement of a bubble screens as planned.

Based on above conclusion regarding sediment transport, turbidity changes the following conclusions are drawn on the potential impact on the environment:

Dredging works will impact living organisms at the dredged site and deposit- sites, and covers a total area of 1-2 ha (dredged and deposit site). Recovery is likely to occur over time if environmental conditions permit. This may take up to several years in case of removal of large corals or well-established seagrass beds. Organisms such as corals, sea urchin and fishes using the breakwater for sheltered may be affected on the short-term (Figure 6.1).

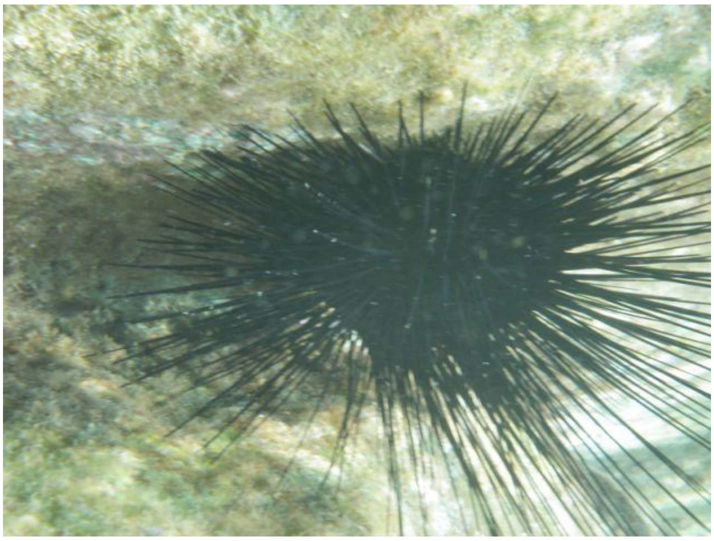

Figure 6.1. Diadema antillarum on the St. Eustatius harbour breakwater (Photo: J. Berkel, STENAPA).

The sediment that enters the water during dredging works is largely assumed to settle immediately, leading to limited sediment-plumes and turbidity. No mayor or irreversible impact from dredging works is to be expected on surrounding habitats. This is based on the assumption that silt and mud is not present at the site. However, if so, habitats up to 1-2 km north of the harbour can be affected. The impact will likely be limited due to the minor expected volumes.

During the deposition of the sediment, no mayor impact on surrounding habitats is expected due to the limited dispersion and mitigation measures taken.

6.1.2 Pile driving and placement of moorings: underwater noise

The amount of sound produced during pile driving and placement of moorings will be limited both in level and duration. The timing also places construction outside the humpback season. No serious short or long-term effects on marine mammals can be expected. No immediate or long-term measurable negative effect on cetaceans in the vicinity should be expected.

6.1.3 Ship movements and marine mammals

No measurable increase in vessel strike risk to marine mammals will take place during the construction phase of the project.

6.1.4 Impact on historical monuments

The two mapped ruins most closely located to the dredging site will be buried under part of the construction. This will result in an effective protected from erosion.

6.2 Long term impact

6.2.1 Dredging and deposited sediment

Over longer timescales, removing the hard layer will probably lead to higher turbidity in the harbour during storms. The winter storms are associated with southward currents, and therefore some of this sediment may be transported south of the wind breaker. The dredge deposit south of the wind breaker and south of the old harbour will probably erode and be dispersed during storm conditions. Shelter from the winter storms implies that the deposit south of the windbreaker only erodes during hurricanes. The rate at which the deposits erode, and how much they contribute to overall turbidity during the storm, cannot be predicted.

An adverse impact of the deposited sediment over longer timescales on surrounding habitats cannot be excluded. Erosion of the southern deposit during storm events or hurricanes is likely to occur. The rate of the erosion and fate of the suspended sediments cannot be predicted. Information on background levels of suspended sediments is lacking.

This means that is cannot be ruled out that an extra total volume of 7000 m^3 sediment can be transported towards the southern reserve during a single hurricane event, potentially smothering coral and seagrass habitats. This might lead to severe impact on some species of corals and sea grasses. A significant part of the southern reserve is covered with these species. Density of the various species is not reported, and impact can therefore not be quantified.

Most corals species in the southern reserve have a low estimated sensitivity to short increased sediment load. However, their sensitivity to burial and long term increased SPM is high, meaning corals will be severely affected in the worst case scenario of smothering by sediments. Recovery is only possible over years, starting with new recruitment. This might however be hampered due to smothered hard substrate

Most sea grasses can tolerate some seafloor elevation due to sediment deposition. Smaller pioneer species are very sensitive to even the smallest amounts of sedimentation, but are expected to recover quickly without negative effects for the ecosystem. For the larger climax species that can tolerate significantly more sedimentation, recovery may take up to several years once they are lost, with considerable negative consequences for the ecosystem and its surroundings.

6.2.2 Ship movements

Long-term effects on marine mammals due to increased use of the harbour can entail some disturbance due to increased sound levels. These are not expected to be heavy or irreversible. Royal Haskoning presents projections of increased vessel traffic to the St. Eustatius harbour based on the current renovation activities (Kateman and Bos 2010). The projected increase in vessel traffic to the St. Eustatius harbour (Kateman and Bos 2010) will largely involve small and relatively slow-moving vessels. This should present no immediate or irreversible threat to cetaceans.

With increased vessel movements increased risk of pollution by chemicals (fuel, oil, bilge water), nutrients and marine litter, and introduction of invasive species (bio pollution) occurs. The overall impact of pollution is considered to be a risk, but cannot be quantified.

6.2.3 Pollution

Pollution by chemicals caused by maritime transportation and harbour activities can have various effects, but most likely the spills are relatively small and dilution will take place. Pollution effects are not likely to manifest on the ecosystem level. Increased nutrient levels affect the composition of primary producers. Seagrass habitat can be affected due to elevated growth of epiphyte algae. Potential increase of marine litter is hard to quantify, as is the relation with harbour visits. Its effects on the ecosystem can however be widespread. Monitoring and mitigation via harbour collection service should be considered an option.

The increased risk of the introduction of invasive species via increased (regional) shipping should be considered a serious aspect. The risk can be quantified via IMO guidelines, but proper monitoring program is needed in order to quantify the actual risk. Even when risk is low, the impact of invasive species can be large, depending on the species and its role in the environment. Monitoring should be considered an option.

6.2.4 Impact on historical monuments

Along with sea-level rise and island subsidence, the construction of the St. Eustatius harbour has already been implicated as one of the key probable causes in the rapid erosion of the shore-side beaches and historical sites of the Lower Town beach area of St. Eustatius (Kateman and Bos 2010). This is believed to be due to the likely fact that the harbour jetty abuts out to sea and diminishes the long-shore sediment transport needed to revitalize the beaches and shores that are subject to the erosive action of waves. This causes damage to the beaches of an area with high tourist potential. Deeper water resulting from dredging allows for higher wave amplitude. Along with increased boat traffic and resulting wakes, this may form a slight additional danger for historical ruins located along the shore due to potential shoreline erosion. However most historical ruins are along the shore in more northerly direction from the to be dredged harbour site. Our best preliminary judgement of likely long-term effect of dredging suggests there to be little additional risk to the archaeological heritage of St. Eustatius due to dredging alone.

These potential effects are also not an acute threat to the historical sites indicated. The possibility to take other mitigation measures to stabilize the historical archaeological sites remains open. Measures may include: wake restrictions for vessels using the harbour, the use of reef balls to reduce wave action, and facilitate sediment deposition or the construction of protective barriers.

7 Outlook and recommendation

Besides the intrinsic ecological value of the habitats of the southern reserve, the southern reserve holds many important dive sites. The environmental quality of the southern reserve habitats is therefore of high importance to the economic prospects of St. Eustatius. Any risk of deterioration of the southern reserve through resuspension of the dredged material and deposition within the southern reserve should be considered with caution and necessary preventive actions should be taken.

Preventive actions related to the planned activities should focus on the deposited sediment in the south and lack of information on silt and mud content. Suggestions are:

- Retrieve information on fine particles such as silt, mud and chalk content in the dredging area
- Make sure sediment deposits cannot erode towards southern reserve. Proper constructions should be considered with the contractor and island bureau
- Halt dredging and deposit activities temporarily in case of elevated seawater temperatures and during rough seas (to avoid multiple stress)
- Monitor surrounding habitat quality (reefs and seagrass) over time
- Monitor future use and related pressures and mitigate as considered needed

7.1 Wider scope of the project

The Lower Town shoreline of Orange Bay has important ecological, archaeological and touristic values, which are potentially critical to the sustainable economic development of St. Eustatius. Because these values are threatened by their vulnerability to ocean conditions, it is recommended to the island government to develop and apply an integrated coastal zone management plan.

In that context this harbour extension project should not be seen as one of so many isolated projects, but should be incorporated into a larger plan to develop and use the coastal area sustainable for optimal long-term benefit, while simultaneously developing measures to safeguard the values represented.

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